The construction of cofferdams Dam No. 26, Alton, Illinois

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THE CONSTRUCTION OF COFFERDAMS

DAM NO. 26, ALTON, ILLINOIS

BY

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A

THESIS

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Approved by ..Joe B Butler..

Professor of Civil Engineering

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AERIAL VIEW
PHOTO BY AIR CORPS
U.S. ENGINEER OFFICE ST. LOUIS, MO.
DEC. 20, 1937 No. 3202

INTRODUCTION

This report is intended to serve as a record of the procedure followed by the Engineering Construction Corporation in the construction and removal of the three cofferdams used during the construction of the Alton Dam with resulting problems, progress and costs.

The site of Dam No. 26, the Alton Dam, is in the Mississippi River at Alton, Illinois, about twenty-three miles upstream from St. Louis, Missouri, and about two hundred and three miles upstream from the mouth of the Ohio River. The dam is upstream from the Clark Highway Bridge and the Missouri and Illinois Bridge and Belt Railroad Company. The movable section of the dam, 1724 feet in length, extends from the river wall of the auxiliary lock on the Illinois side of the river to the Missouri shore. (See Frontispiece.)

The original elevation of the Missouri bank of the river along the dam site was 414 mean sea level. As a start of construction this was raised to elevation 424 mean sea level by means of a hydraulic dredge over the triangular area which ajoins the Missouri abutment. The extreme highwater mark of 1844 reached elevation 432.5 M.S.L. and the extreme low water mark of 1933 reached 393.8 M.S.L. Borings indicated that the underlying strata were composed of lenticular deposits of sand varying unevenly from very fine to coarse, in some cases mixed with a small percent of gravel.

A cofferdam is defined as a temporary inclosing dam constructed of earth, wood, or steel sheeting, or a combination of these, built in the water and pumped dry for the purpose of expediting the construction of subaqueous footings or foundations. This term is usually applied to large inclosures, there being practically no limit to the extent of the area.

The specifications stated that cofferdam protection should be provided in three separate sections, (see Fig. 1). It provided that the first section of the cofferdam should inclose an area for the construction of the Missouri abutment and twelve Tainter gates adjacent thereto; the second section should inclose an area for the construction of six Tainter and three roller gates; the third section should inclose an area for the construction of twelve Tainter gates adjacent to the riverwall of the auxiliary lock.

The specifications required that except for the inclosure of the Missouri abutment in the first section, all cofferdams should consist of cells of interlocked steel sheet piling, filled with sand or other suitable material. The cofferdams were required to be constructed with top at elevation not lower than 415.0 M.S.L. and not higher than 416.0 M.S.L. If the type of cofferdam specified was not satisfactory to the contractor, he could, with the approval of the contracting officer, build any other type of cofferdam, provided however that the substituted structure should provide at

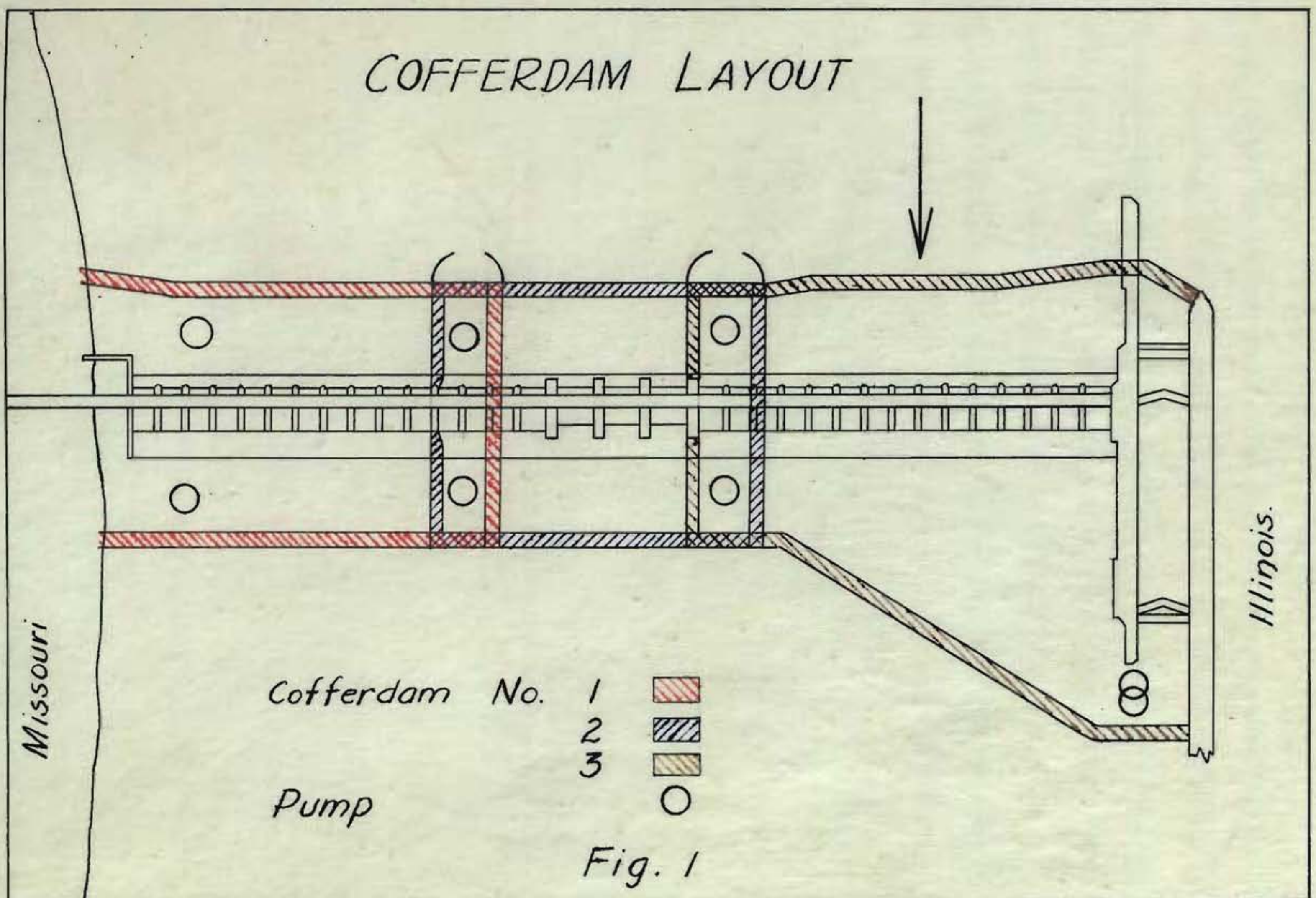


Fig. 1

least equal protection and stability, and that the cost to the United States should not exceed the total contract price for the type specified. The contractor should submit, for the approval of the contracting officer, prints in triplicate showing plans of the cofferdam he proposed to erect, method of unwatering, layout, and pump capacity, before making any provision for its construction. The design should be in accordance with sound engineering practice and load assumptions as approved by the contracting officer.

DESIGN OF A COFFERDAM

The contractor, The Engineering Construction Corporation, submitted for approval his design of the cofferdam. Instead of cellular type cofferdam, this was one of two parallel walls of Carnegie steel sheet piling, section M115, tied together with tie-rods with inside and outside supporting berms. (See Fig. 3)

The following shows the design of the cofferdam walls:

Analysis of Design

A. Data and Assumption

1. Sand

Dry packed	112 lb./ cu. ft.
Saturated	133 lb./ cu. ft.
In water	70 lb./ cu. ft.
Absolute density	2.65
% Voids	33

(a) Slopes - Dry 1:1-1/2 $\phi = 33^\circ 41'$

$$\tan^2\left(45^\circ - \frac{\phi}{2}\right) = 0.2864$$

Saturated 1:3 $\phi = 18^\circ 26'$

$$\tan^2\left(45^\circ - \frac{\phi}{2}\right) = 0.5195$$

$$\tan^2\left(45^\circ + \frac{\phi}{2}\right) = 1.9249$$

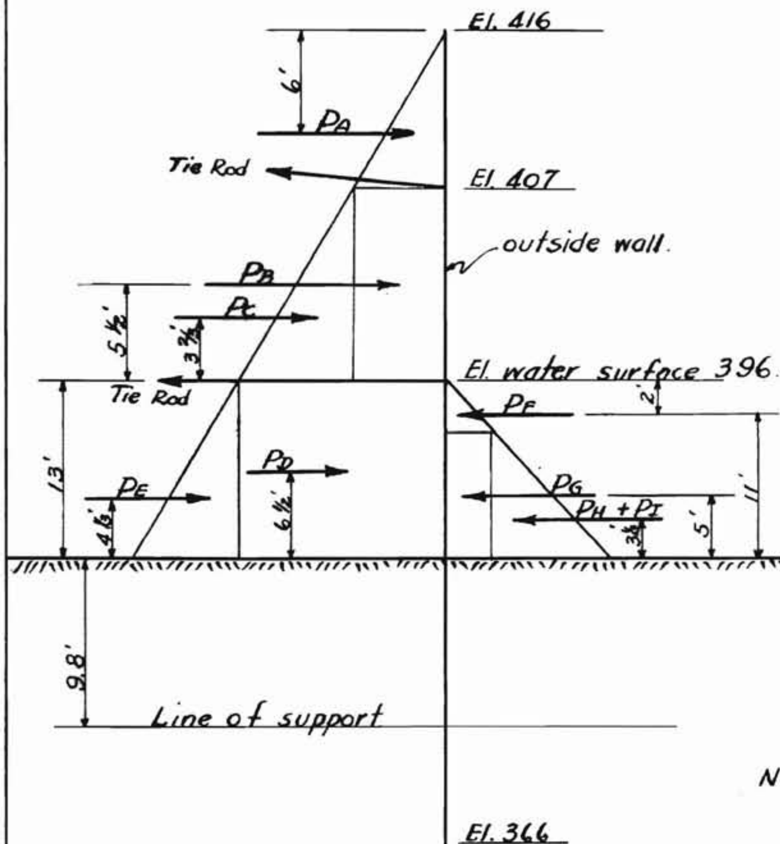
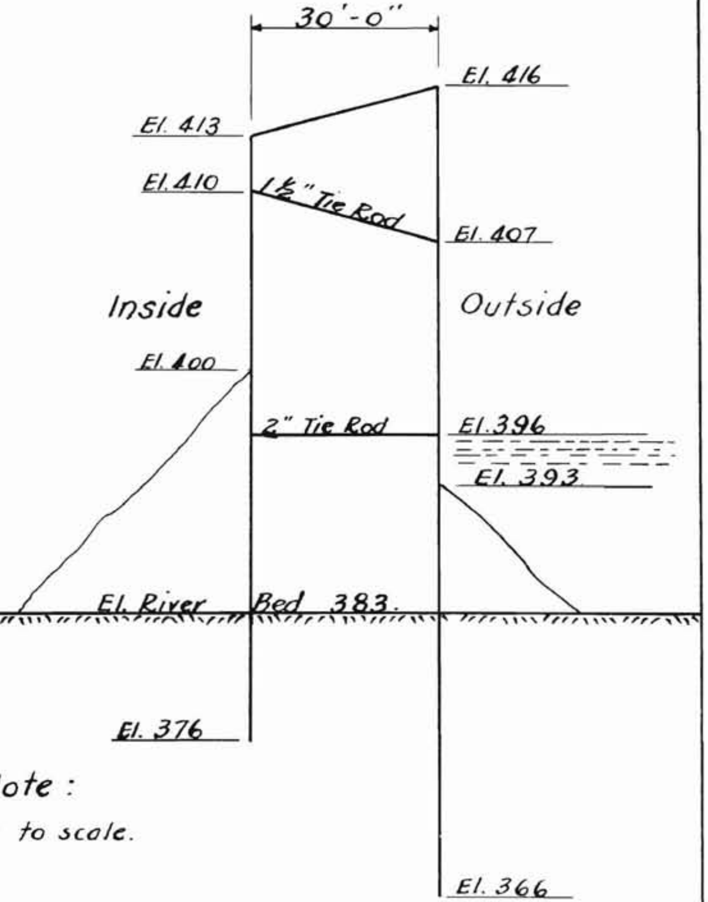


Fig 2



Note :
Not to scale.

Fig 3.

(b) Lateral pressure - equivalent liquid pressure

Dry 112 x 0.2864 = 32.08 lb./ sq. ft.

Saturated 113 x 0.5195 = 69.09 lb./ sq. ft.

Submerged 70 x 0.5195 = 36.36 lb./ sq. ft.

(c) Passive (submerged) 90 x 1.9249 = 134.7 lb./ sq. ft.

B. Load Analysis (See detail - Fig. 2)

1. Assume water surface elevation = 396.0 at time dredge pumps sand in cofferdam

$P_A = \frac{69.09}{2} (416 - 407)^2 =$ 2798 lb. sat. sand

$P_B = 69.09 \times 9 \times 11 =$ 6840 lb. sat. sand

$P_C = \frac{69.09}{2} (407 - 396)^2 =$ 4180 lb. sat. sand

$P_D = 69.09 \times 13 \times 20 =$ 17,963 lb. sat. sand

$P_E = \frac{69.09}{2} (396 - 383)^2 =$ 5837 lb. sat. sand

$-P_F = \frac{62.5}{2} (396 - 393)^2 =$ 281 lb. negative water pressure

$-P_G = 62.5 \times 3 \times (393 - 383) =$ 1875 lb. neg. water pressure

$-P_H = \frac{36.36}{2} \times (393 - 383)^2 =$ 1818 lb. neg. sub. sand fill

$-P_I = \frac{62.5}{2} \times (393 - 383)^2 =$ 3125 lb. neg. water pressure

$-P_P = \frac{134.7}{2} \times (383 - 366)^2 =$ 19,645 lb. passive (submerged) pressure

C. Thrust Cofferdam Can Withstand Without Bracing

Steel sheet piling - Carnegie Steel Company - Section M115 was used.

$$\frac{I}{C} = 5.4 \text{ in.}^3$$

$$M = \frac{SI}{C}$$

S = 20,000 lb./ sq. in.(safe working stress)

M = 20,000 x 5.4 = 108,000 in. lb. (max. bending moment cofferdam can resist without bracing)

Cofferdam as a cantilever beam with uniformly increasing load.

M = 4 PH

H = Distance from top

M = Bending moment, in. lb./ft. width

$$P = \frac{M}{4H} = \frac{108,000}{4 \times 33} = 818$$ lb./ft. width (load cofferdam can resist without bracing)

D. Stress in Upper Tie Rod

$$P/\text{ft. width} = 2798 + \frac{6840}{2} + \frac{4130}{3} = 7591 \text{ lb.}$$

P total = 7591 x 9.8125 = 74,487 lb.(acting horizontal)

Tie rod acts at an angle whose tan = 0.10 (angle = $5^{0}42.63'$)

Stress in tie rod then = 74,487 x sec $5^{0}42.63'$ =

74,487 x 1.005 = 74,859 lb.

1-1/2" dia. rods provided - cross sectional area = 1.767

$$\text{Unit stress in steel} = f_s = \frac{74,859}{1.767} = 42,365 \text{ lb./sq.in.}$$

$$\text{Factor of safety against failure} = \frac{70,000}{42,365} = 1.65$$

E. Stress in Lower Tie Rod

$$P/\text{ft. width} = \frac{6840}{2} + \frac{4180 \times 2}{3} + \frac{17{,}963}{2} + \frac{5838}{3} - \frac{11}{13}(281) - \frac{5}{13}(1875) - \frac{3.33}{13}(4943) = 14{,}908 \text{ lb.}$$

818 lb./ft. width = load cofferdam can resist (no bracing)

818 lb./ft. width = negative pressure acting elev. = 394

$$P = 14{,}908 - 818 \times \frac{11}{13} = 14{,}216 \text{ lb./ft. width}$$

$$P \text{ total} = 14{,}216 \times 9.8125 = 139{,}495 \text{ lb.}$$

2" dia. rod provided = 3.1416 sq. in.

$$\text{Unit stress in steel} = f_s = \frac{139{,}495}{3.1416} = 44{,}400 \text{ lb./sq.in.}$$

$$\text{Factor of safety against failure} = \frac{70{,}000}{44{,}400} = 1.6$$

F. Upper Wales (Shear)

Max. load on ties = 74,487 = shear

6" x 20" washer distributed load over area

$$\text{Max. shear} = \frac{74{,}487}{6} = 12{,}415 \text{ lb.}$$

Provided 2 - 10" x 12" timbers = 240 sq. in. sectional area

Max. allowable shear for timbers = $\frac{4}{3} \times 240 \times 110$ (southern yellow pine) = 35,200 lb.

Max. allowable shear for washer = 1/2 x 3 x 3000 = 4,500 lb.

35,200 + 4,500 = 39,700 lb. (max. allowable shear in wale)

G. Lower Wales (Shear)

Max. load on ties = 139,495 lb. = shear

6" x 20" washer distributed load over area

Max. shear = $\frac{139,495}{6}$ = 23,249 lb.

Provided 2 - 10" x 12" timbers = 240 sq. in in sectional area

Max. allowable shear = 39,700 lb.

H. Upper Wales (Bending)

Assume wales as a simple beam with uniformly distributed load

w = Load = 7591 lb./ft.   l = 9.8125 ft.

$M_{max} = \frac{w\ l^2}{8}$

$S = \frac{MC}{I} = \frac{7591 \times (9.8125)^2 \times 12 \times 6}{8 \times 20 \times 12 \times 12} = 2284$ lb./in

Modulus of rupture for wood = 8700 lb./in.

Factor of safety = $\frac{8700}{2284}$ = 3.8

I. Lower Wales (Bending)

w = Load = 14,216 lb./ft.   l = 9.8125 ft.

$M_{max} = \frac{w\ l^2}{8}$

$S = \frac{MC}{I} = \frac{14,216 \times (9.8125)^2 \times 12 \times 6}{8 \times 20 \times 12 \times 12} = 4277$ lb./in.

Factor of safety = $\frac{8700}{4277}$ = 2

This plan received approval. The sheet piling proposed to be used was Carnegie Steel Sheet Piling section M115, 3/8" web 36.0 lbs. per lineal foot and 19-5/8" wide with strength of 8000 lbs. per lineal foot in interlock. Generally on the upper and lower arms of a cofferdam 50 ft. sheet piling was used on the outside and 37 ft. sheet piling on the inside, except in the case where the elevation of the river bed warranted longer piling. In the outer arm 60 ft. sheet piling was used on the outside and 37 ft. on the inside. (See Fig. Nos. 15, 16, 17, for actual length used in each wall).

CONSTRUCTION OF FIRST COFFERDAM

Conditions altered the proposed areas of the inclosures of the cofferdams. In the first section the area specified was adhered to. In the second section the area cared for 4 roller gate piers and 3 Tainter gate piers instead of the 4 roller gate piers and 6 Tainter gate piers. In the third section provision was made to make an inclosure to take care of the remaining 13 Tainter gate piers and also the river wall of the auxiliary lock, which was contracted for after the dam was under construction. (See Fig. 1 for layout.)

Construction began on Cofferdam No. 1 on June 28, 1935. At this time the water elevation of the river was ranging between 414.0 and 417.6 M.S.L. Since the grade on the outside sheeting was 415.75 and on the inside sheeting 413.0, this high stage of the river necessitated some submarine driving which slowed down the progress of driving considerably.

Driving was started on the landside of the upper arm. An ordinary A-frame type skid rig pile driver with 55 ft. fixed leads mounted on a 30' x 100' barge and using a No. 1 Vulcan steam hammer was employed to drive the 55 ft. timber piles for the cofferdam template. A double row of these pile were driven 20 ft. apart and 15 ft. on centers. Lateral and diagonal bracing was done with 3" x 12" x 30' pine lumber. The template extended 5 ft. outside of each row of piling, making a total width of 30 ft. The steel sheet piling was set flush against the template on each side. The maximum elevation of the template was determined by the water and the mimimum by the elevation of the top tie rods. (See Fig. 4.)

The template was not advanced more than about 100 ft. ahead of steel placing for two reasons; first, a possible rise in the river would cover the template, and second, damaging scour would occur where unprotected timber piling stood too long in the current.

The template not only served to act as a form to place steel sheeting against and to hold the sheeting in a rigid position until the cofferdam filling took place, but also afforded an excellent scaffold for the workmen to use in placing sleeves, tie rods, wales (or walers), etc.

Five-and seven-pile clumps for anchorage were driven about 100 ft. above the upper arm and about 150 ft. centers to facilitate construction on the upper arm. A number of 4000-pound concrete anchors were also used to hold the rigs in the desired position. Such methods were not used on the outer and lower arm and at lower river stages.

Some of these template piles were pulled with a Vulcan No. 400-A pile extractor, but this procedure was soon abandoned. The bracing timber was removed before the sand fill reached a height to hinder such work.

Several things were learned in the driving of the timber piling. Considerable breakage was experienced in the driving of the

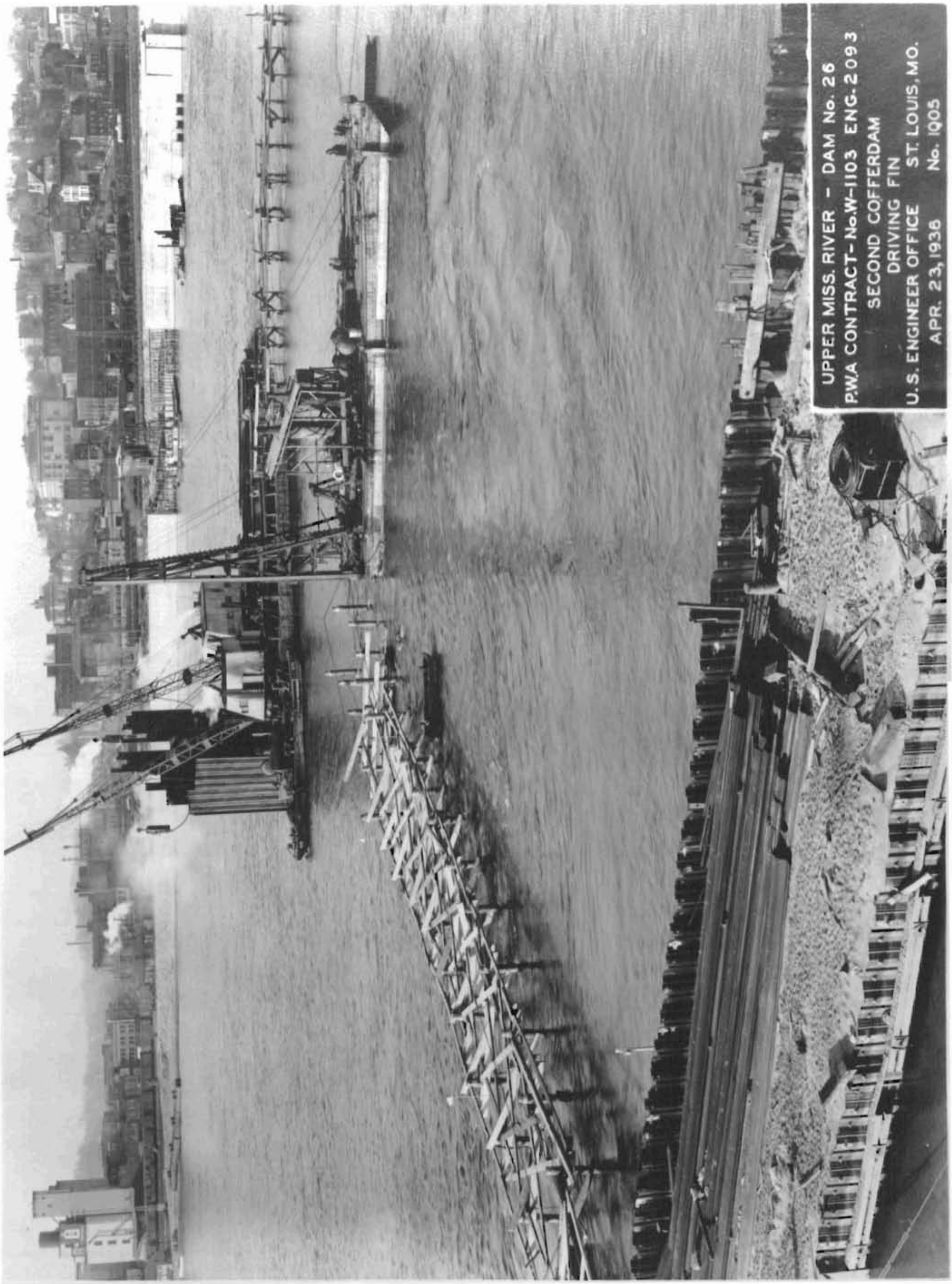

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG. 2093
SECOND COFFERDAM
DRIVING FIN
U.S. ENGINEER OFFICE ST. LOUIS, MO.
APR. 23, 1936 No. 1905

Fig. 4

55 ft. timber piles because they were too slender for the 9600 pound Vulcan hammer. A No. 2 Vulcan hammer would have been more desireable for these piles.

The alignment of the piles was poor due to the fact that the driver was mounted on a barge with a 6 ft. of freeboard which made spotting more difficult than one mounted on a barge with an 18" to 2' freeboard.

The Vulcan pile extractor No. 400-A was too small to pull the timber piles. It is possible to have a hammer too large for the piling being driven but it is very seldom that damage results from an over size extractor.

The steel sheet piling was set and driven with two Wiley Whirley cranes. Rig No. 1 worked on the outside wall and Rig. No. 3 worked on the inside wall, except for a few days in the beginning when Rig. No. 4, a gas engine Speed crane with an auxiliary boiler for Mck-T 9B hammer, set and drove on the inside wall of the upper arm.

The procedure on the upper arm was for Rigs Nos. 1 and 2 to work together on placing the tie rods, sleeves and wales. This procedure utilized practically as much time as setting and driving the sheeting. The worst condition may be shown in the case where the water elevation was at 417.

The bottom rods were placed at elevation 396, which meant that the length of the sheet which had to be above the water at all times was 20 ft. on the outside and 17 ft. on the inside. In this case there was 37 ft. of water which indicated that the distance from the river bed to the bottom of the sheet was 7 ft. on the outside and 20 ft. on the inside. The friction developed in the interlocks was not sufficient to hold these sheets up in position so they were held by fastening them to an adjacent sheet with an ordinary harness trace chain.

The top tie rods were placed at elevation 407 on the outside and 410 on the inside which meant that the length of the sheet that had to be above the water to place the rod was 9 ft. on the outside and 3 ft. on the inside. At this point the outside sheet had 4 ft. of penetration and the inside sheet was still 3 ft. above the river bed. This distance of 34 ft. in the interlock did not develop enough friction to hold the sheet up so it had to be tied with a trace chain the second time. When the progress of the upper arm had reached the midway point, clamps fastened to the interlock were substituted for the trace chains. At no time could the bottom rods be placed after the sheeting was driven to grade, and not until the water elevation reached 407, which was at the beginning of the lower arm, could the top rods be placed after the sheeting was driven to grade.

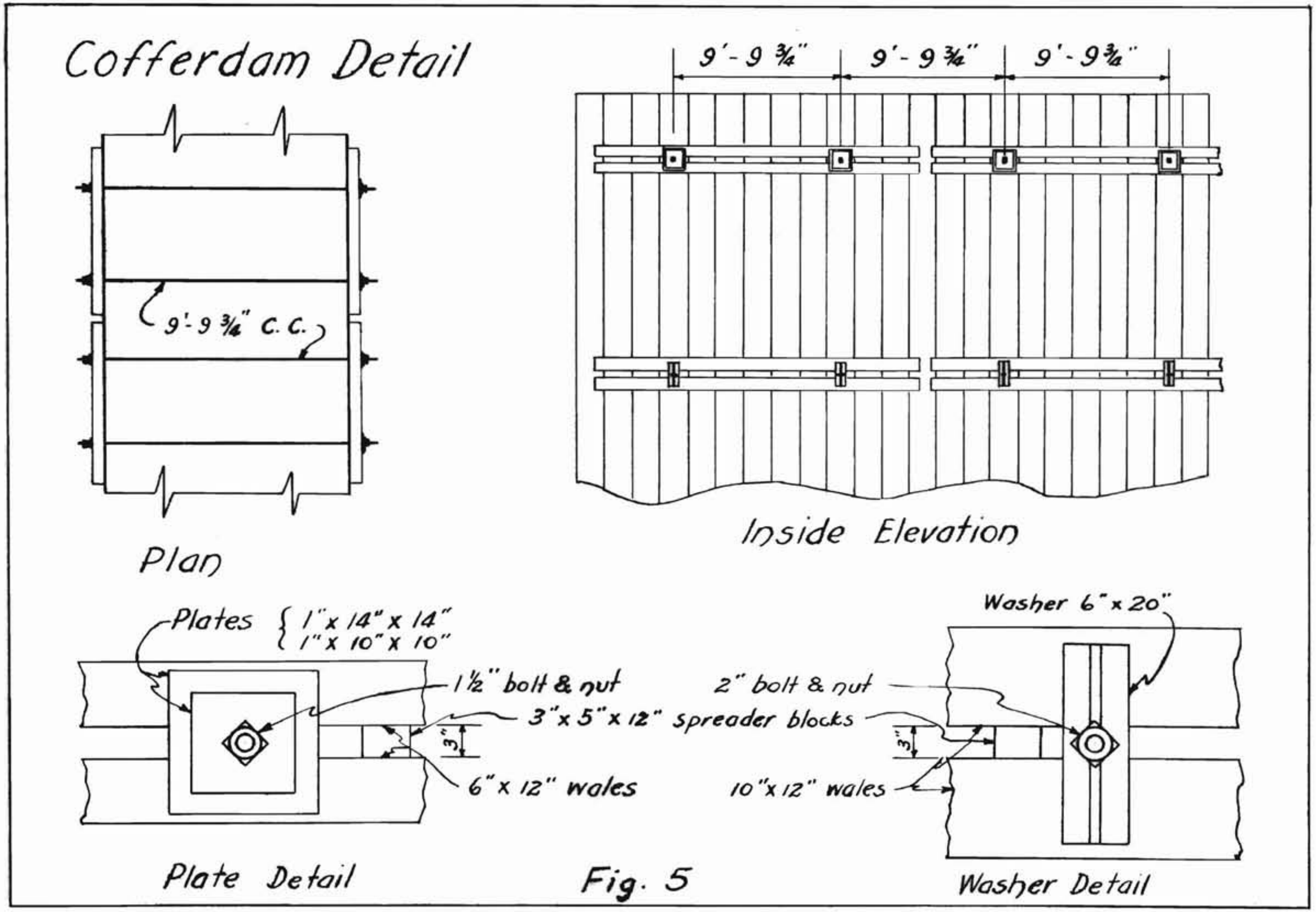
The top tie rods were 1-1/2" x 34'6" and the bottom tie rods were 2" x 34'6". The sleeves or spreaders were made of a 30 ft. section of 3" iron pipe. These spreaders were used on the bottom tie rods. The spreader was lowered into position on the inside and the 2" rod inserted from the outside through the spreader. The top rod was placed from the inside, allowing one end to project through the hole in the sheeting while the other end was inserted through the opposite row of sheeting.

Tie rods in practically all cases were placed in every sixth sheet giving a distance of 9' 9-3/4" center to center. Each pair of rods were bolted to an 18' 6" long horizontal waler on each side, leaving a theoretical space of 13-1/2" between the ends of each waler. (See Fig. 5, for cofferdam detail)

Since the tie rod holes in the sheeting were 1/4" larger than the rod, a 3/8" x 8" x 22" washer cut from old rubber belting was placed over the rod between the waler and the sheeting on the bottom outside, for the purpose of preventing seepage or infiltration of water around the tie rod. A 6" x 20" cast iron washer was used to transmit the strain from the rod to the wale below inside, and above and below outside. On the upper inside wale two plates 1" x 14" x 14" and 1" x 10" x 10" were used.

The two lower wales and the upper outside wale were made of two 10" x 12" timbers separated by four 3" x 5" x 12" pieces. This 3" space permitted the insertion of the tie rods. The upper inside wale was made of two 6" x 12" timbers separated by four 3" x 5" x 12" pieces.

After the rods were in position the wales were slipped over the ends of the rods with the aid of one of the cranes.



Cofferdam Detail
9'-9 3/4"
9'-9 3/4"
9'-9 3/4"
9'-9 3/4" C.C.
Plan
Inside Elevation
Plates { 1" x 14" x 14" / 1" x 10" x 10"
1 1/2" bolt & nut
3" x 5" x 12" spreader blocks
2" bolt & nut
Washer 6" x 20"
3"
3"
6" x 12" wales
10" x 12" wales
Plate Detail
Washer Detail

Fig. 5

A pile driver crew consisting of one foreman, one engine man, one fireman, two leadsmen and two deck hands could, on the average, drive the tie rod sheets only and place 8 sets of rods and wales per 10 hour shift, depending on the number of sleeves, a set consisting of two wales, two rods and on the alternate bottom wales, two sleeves. This equaled 4 double sets (top and bottom) per shift or in terms of lineal feet of cofferdam, it amounted to 78.5 . The minimum time recorded by the writer for any single set, consisting of two wales, two rods and two sleeves was one crew hour.

Practically all of the work on the outer and lower arms fell to the lot of Rig No. 3. However, this rig did not maintain the aforementioned average of 78.5 ft. per 10 hour shift because Rig No. 1 left practically all of the sheets partially driven to grade to be finished by Rig No. 3.

In driving the wale or rod sheets on the upper arm where both rigs were working together, it was customary for both hammers to drive on the same wall; that is, on the same wale rather than on opposite walls or on sheets on the same rod. The reason for this was that when the sheets were driven with the wale maintained in a horizontal position, one wale could be driven a maximum distance of 5 ft. below the one on the opposite wall giving a total driving distance of 10 ft. because the walls were 30 ft. apart. If the sheets were so driven that the ends of the wale went down alternately, one end could not be more than 2 ft. lower than the other, giving a total driving distance of 4 feet due to the rods being spaced 9 ft. 9-3/4 in,c.c.

This procedure was abandoned in the outer and lower arms and driving was done with a single rig moving its hammer progressively around the 4 sheets connected with the 2 wales and 2 tie rods above and below. The McK-T No. 9-B hammer was used practically altogether on this phase of driving.

The steel sheet piling was shipped to the job by barge, each barge containing about 500 tons. These barges were placed along side of the rigs and the Whirleys picked up the piles as they were needed.

The threading was done by a leadsman standing in steel stirrups hooked over the adjacent pile. It was common practice to thread 40 or 50 sheets on each wall and then pick up a McK-T No. 7 hammer with the pile line and drive these sheeting about half or two thirds way to grade. The rig following used the larger No. 9-B hammer to complete the more difficult driving to grade. The hammer was placed over the intersection of 2 sheets and both were driving simultaneously. Where a single sheet was driven, considerable upsetting of the top of the pile was experienced, necessitating removal of 6" to 12" with an oxyacetylene torch.

At varying intervals on each arm a diaphragm was set across each arm. This was a wall of sheeting set and driven between the inside and outside walls of an arm to maintain a more stable sand fill, and also to facilitate in the removal and construction of following sections. A T-section placed in the outside and inside walls made the connections for the diaphragm.

Work on the driving of cofferdam No. 1 progressed as follows: the upper arm began at the Missouri bank and extended riverward until the end was reached at Sta. 8 ⱡ 30 from base line; at this point the outer arm began and extended downstream until the lower outstream corner was reached; the lower arm began at the Missouri bank and extended riverward. An 80' gap was left at the lower outstream corner from Aug. 9 to 13 to permit removal of the floating plant inside the inclosure. The completion of sheet setting was reached on Aug. 14 and driving on Aug. 15.

Several difficulties were encountered during the construction of the first section of cofferdam. On the upper arm when the steel setting had reached a point at about sta. 2ⱡ50 the velocity of the current began to increase appreciably resulting in scour which varied from 2' to 8' up to Sta. 7ⱡ00 at which point the scour increased abruptly, reaching a maximum of 30' below the original ground at the outer corner. Although 60 ft. sheeting was used on the end of the outside wall, at this point the river bed was 4 ft. below the bottom of the sheeting. This condition was due to the restriction of the river channel and the high river stage at this time resulting in the high velocities. The Alton stone trailer dike in place above the dam afforded very little protection due to the high stages of the river.

The use of a streamlined deflector fin was incorporated in the cofferdam design. This was based upon the efficacy of its use in model studies sponsored by Spencer, White & Prentiss and conducted at the University of Minnesota. Thru the use of a properly designed fin projecting upstream it was clearly shown that damaging river velocities with their attendant scour were moved far enough streamward as to materially protect the outside cofferdam wall for a distance of three or four hundred feet downstream. (See Fig. 6)

The driving of a streamline fin was attempted at this time for the purpose of current deflection but construction never progressed farther than driving 7 sheets at which time the 15 - 55 ft. timber piles and template scoured out. Prevention of further scour was attempted by casting in along the outer end 120 cu. yd. derrick stone, 100 cu. yd. of 1 man stone, and 5500 sand bags with no appreciable results according to sounding records. After a greater portion of the sandbags were cast in, one at a time, a test was made by tying a line to a bag and it was found the velocity of the current was so great that the bag was carried 50 to 60 ft. horizontally before coming to rest on the bottom.

After the river dropped to such stages that protection resulted from the trailer dike, fill immediately occurred. With the decrease in current velocity, fin construction progressed without mishap. It was not until this time that the corner section of the

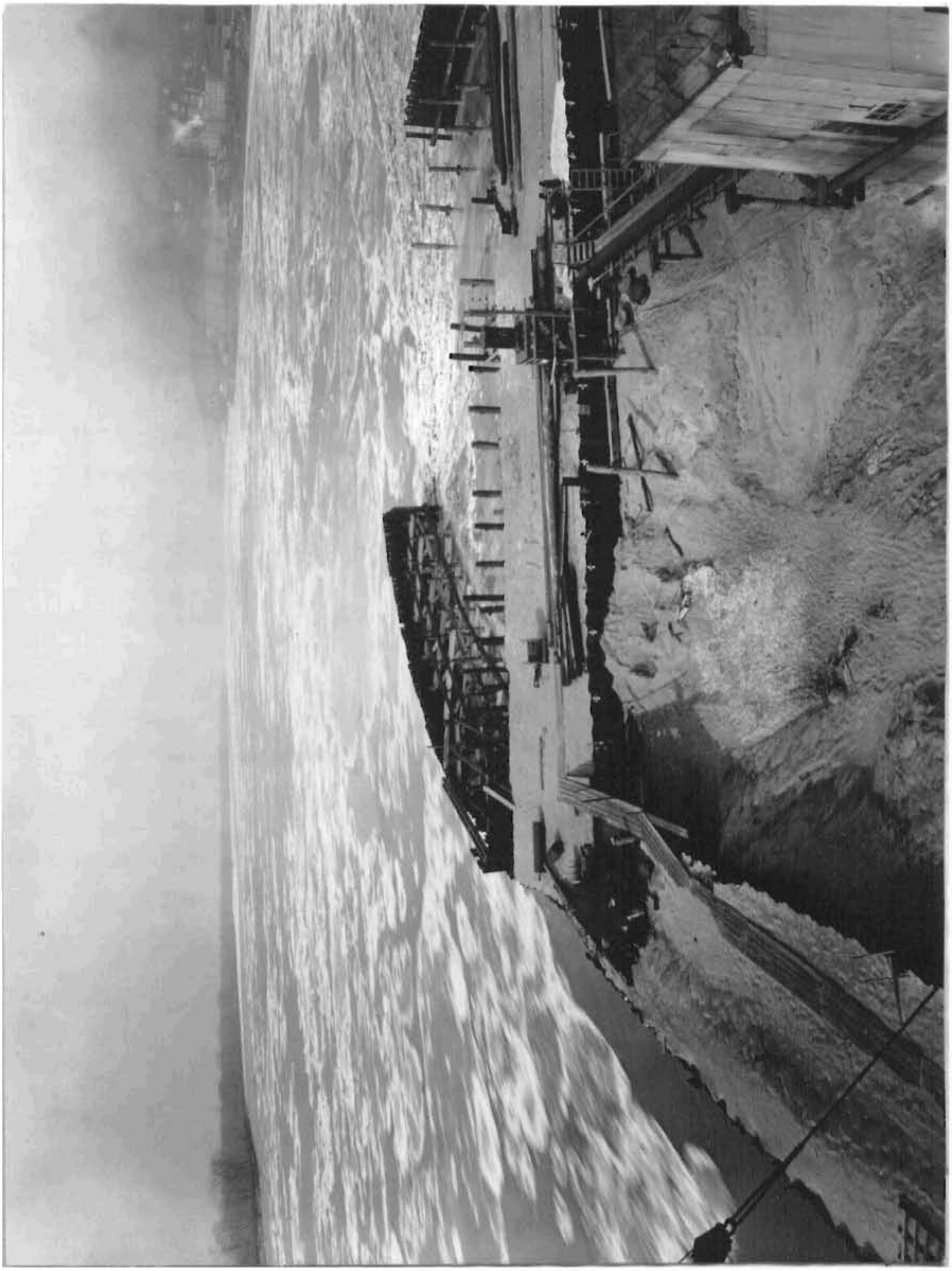


Fig 6

cofferdam could be filled.

This experience indicated that under similar conditions it would be better to build the cofferdam on to the fin rather than build the fin on to the cofferdam. This was the general practice followed on the two succeeding cofferdams. (See Fig. 4)

The alignment of the upper arm was not very good due to difficulties caused by the aforementioned high velocities.

Fill rather than scour occurred along the outer arm due in part to 10" dredge pumping at the corner. No special difficulties occurred in the lower arm as was shown by its almost perfect alignment.

The cofferdam excavation and fill was sublet to the George C. Bolz Dredging Company of St. Louis. A greater portion of the fill was placed by a 16" hydraulic cutterhead dredge mounted on a 30' x 100' steel barge. The Allen-Sherman Huff 15" pump was operated by a 550 H. P. 2200 volt, 60 cycle, 8 phase, 106 amp. 575 R.P.M. Westinghouse Electric motor and the cutterhead was powered by a 125 H.P. Western Electric motor operating the cutter at 24 R. P. M. This dredge had a 45 ft. ladder and could efficiently operate against a 4' - 6' face in 30' of water. Approximately 30% of the total fill was placed by diesel suction dredge with a 40' suction pipe and mounted on a 24' x 60' steel barge. This dredge had a Morse 10" pump powered by a 120 H.P. Fairbanks Morse Diesel engine. This dredge placed 85% of the 30,000 cu. yd. in the berms and 60% of the 60,000 cu. yd. in the cells.

The 16" dredge produced 447 hours out of 30 days giving an average of 62% productive time and the 10" dredge 393 hours out of 21 days or 78% productive time. The entire cofferdam fill and inside berms were made from excavation in the cofferdam area.

CONSTRUCTION OF SECOND COFFERDAM

The second cofferdam was started before the first was flooded. When practically all construction on the dam in the first section was complete, the Missouri arm of the second cofferdam was started inside the first cofferdam. At Sta. 6+47 on the upper and lower arms a row of sheeting was driven with another row paralleling it at Sta. 6+67. All sheeting was driven to grade and braced with tie rods and wales as shown before, with the exception of the sheets which crossed the masonry of the dam.

During the construction of the dam, two channels about 12" wide and 6" deep were left across the apron on the lower side of the dam. After all equipment and forms were moved to the Missouri end of the first cofferdam, the sheeting was continued across the apron set in these channels. There were no channels in the sill on the upper side of the dam. The sheets for the walls lapped the end of the nose of each end of Pier No. 23, where they were then bolted to the pier by bolts extending through the width of the pier. (See Fig. 7). The holes through the pier were holes caused by pipe used as spacers for the forms, and left unfilled.

The moving of the equipment and forms into the inclosed area between the Missouri arm of the second cofferdam and the Illinois arm of the first cofferdam, afforded a protection for this plant and also an economy in handling, inasmuch that the

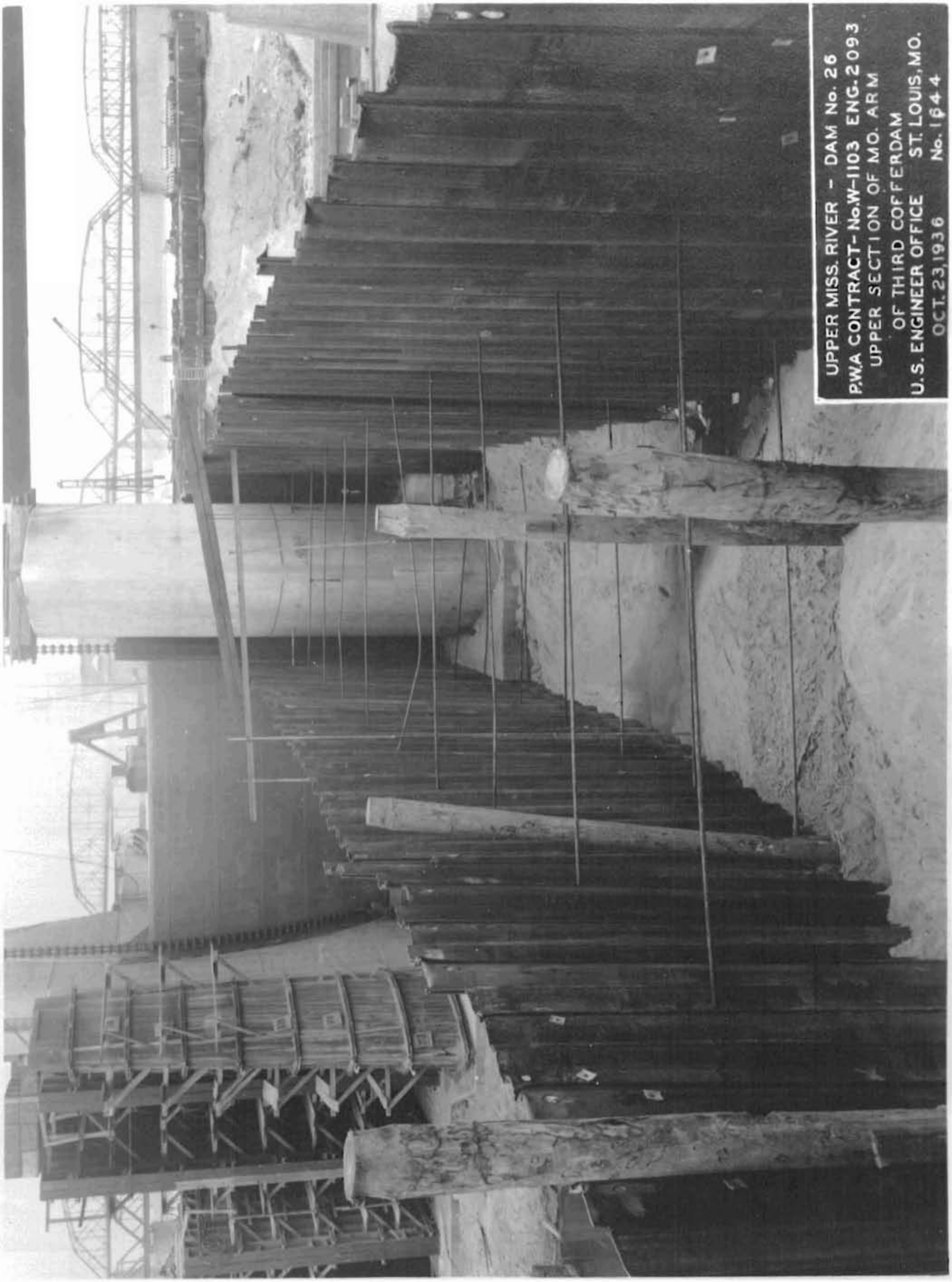

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG.2093
UPPER SECTION OF MO. ARM
OF THIRD COFFERDAM
U.S. ENGINEER OFFICE ST. LOUIS, MO.
OCT. 23,1936 No. 1644

Fig. 7.

equipment would be in place when the second cofferdam was in place.

After the upper and lower arms of cofferdam No. 1 from the Missouri bank to Sta. 6+67 were pulled, the contractor was delayed in starting the remaining part of the second cofferdam due to difficulties arising from the failure of the auxiliary lock cofferdam on the Illinois bank of the river.

However, work was started on the second cofferdam on April 14, 1936. At Sta. 13+12 the streamline fin was first built. The sheets in this were 85 ft. long. A circular cell 30 ft. in diameter was then attached to the lower end of the fin. The rig driving the timber piling for the frame work then continued downstream from this point on the Illinois arm. Another started from the Missouri end of the upper arm and drove to the cell.

Two rigs driving sheet piling started setting and driving from opposite ends of the upper arm. At various times they switched to the Illinois arm, to set and partially drive sheeting along the frame work, as a protective measure against scour.

As the upper arm neared completion, the gap in the walls narrowed down. The current velocity through this hole was very high due to confining the river to a narrower channel. With but a few sheets remaining to be set in this gap, scour became so great that the frame work of timber pile and adjacent sheet piles were undermined and failure occurred. (See Fig. 8)

To prevent further scour rip-rap stone and 1"- 2" stone

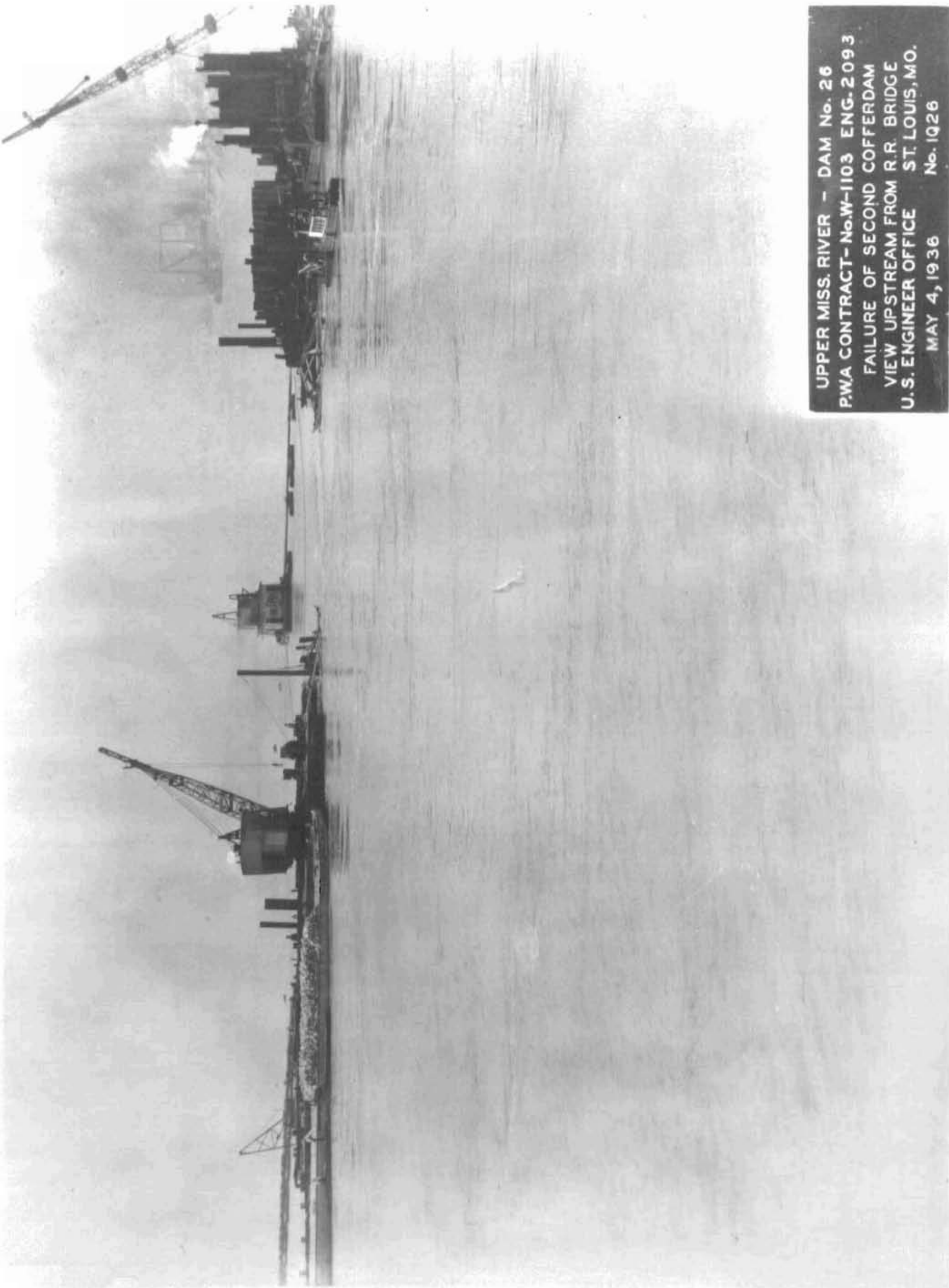

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG. 2093
FAILURE OF SECOND COFFERDAM
VIEW UPSTREAM FROM R.R. BRIDGE
U.S. ENGINEER OFFICE ST. LOUIS, MO.
MAY 4, 1936 No. 1926

Fig. 8

were dumped above the gap. This, however, did not cause any fill to occur.

Several plans were advanced to overcome this unlooked for happening. The plan finally used called for a trestle to be built above the gap and the steel sheeting to be fastened to it and driven. (See Fig. 9.)

The trestle was built with 3 pile bents, the bents being about 6 feet apart. The trestle was built beyond both sides of the failure. Sheet piling were set in a guide to hold the alignment and a cable was attached to the bottom, with a release attachment, and held taut by a pile driver anchored upstream from the trestle. When the sheet was set in place, the cable was slacked off and released. It was used in the same manner on each succeeding sheet. Seventy foot sheets were used in this gap and were anchored to the trestle.

The outside wall was thus completed and the inside wall was then easily set up and driven without any interference from water rushing through. When the arm was filled with sand and quite stable, the outer wall was released from the trestle and most of the trestle removed.

Construction of the Illinois arm and the lower arm was well underway when removal of the Illinois arm of cofferdam No. 1 was started. Sheets removed from this arm were used in the remaining portions of the outer and lower arms. A gap was left

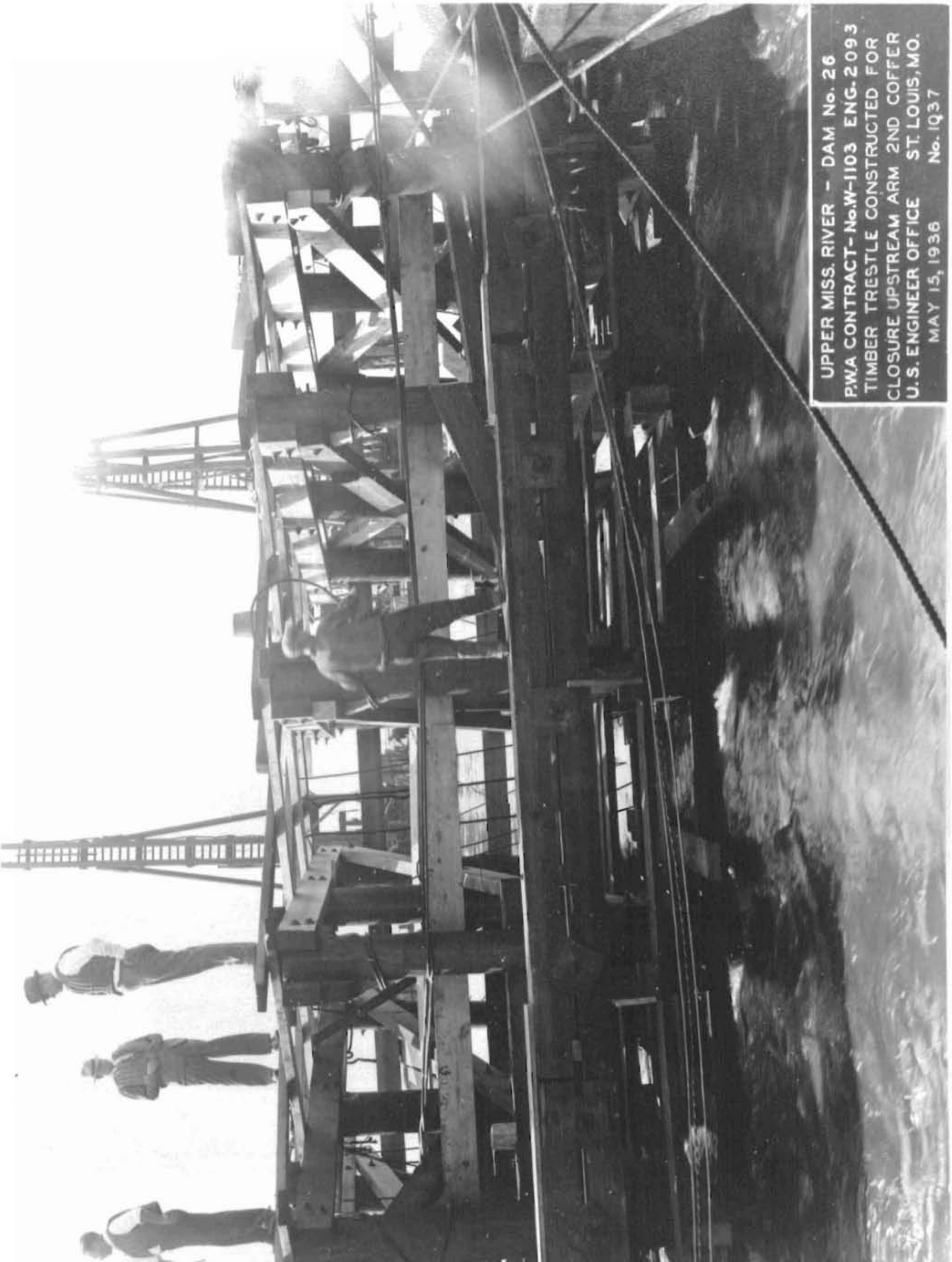

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT - No.W-1103 ENG. 2093
TIMBER TRESTLE CONSTRUCTED FOR
CLOSURE UPSTREAM ARM 2ND COFFER
U.S. ENGINEER OFFICE ST. LOUIS, MO.
MAY 15, 1936 No. 1937

Fig. 9

in the lower arm of this section similar to the first cofferdam to permit the removal of floating plant. When all plant was removed, this gap was closed and pumping down was started.

CONSTRUCTION OF THIRD COFFERDAM

Cofferdam No. 3 was made larger than originally planned to include the riverwall of the auxiliary lock, acquired by contract after the dam was under construction.

The cofferdam of this riverwall of the auxiliary lock as built by the original contractor, the John Griffiths and Sons, was destroyed by ice when nearly complete. Before work could be started on the third cofferdam of the dam, most of the steel sheeting and other wreckage had to be removed.

The U.S. Engineer Dredge Grafton was engaged to remove the fill which had covered this wreckage after a sounding party of the U.S.Engineer Department spent some time locating the position and depth of the wreckage. A pile driver with a jet pipe would sound down until it came in contact with the obstruction and then find its limits. Two transits were set up on the wall and the angles were recorded on each sounding, the depth also being recorded. This was all plotted, giving a very accurate plan and elevation of the destroyed cofferdam.

A large derrick boat, a smaller derrick boat and a pile driver belonging to the U. S. Engineer Dept. were then employed to remove this wreckage. Two divers were let down to the bottom and they burned holes in the steel sheets. A clasp was bolted thru these holes and the sheets were hauled up in sections varying in size from a part of a sheet to sections of several sheets threaded together. (See Fig. 10).

The Missouri arm of the third section of the cofferdam was set up and driven in the same manner as was used in the corresponding arm of the second section, the arm being built and tied to the combination Pier No. 16 before flooding the area.

The upper arm was not straight as were the other corresponding arms. It was started from the upper end of the intermediate wall of the locks on Sept. 28, 1936. On Oct. 14, 1936 work was begun on the Missouri end of the upper arm by driving timber pile for the falsework of the streamline fin. Work then progressed from both ends of the arm.

The cofferdam crossed through the position of the upper guide wall of the auxiliary lock wall, which was to be constructed after the cofferdam was removed. Permanent timber pile were driven in the falsework, being placed in alignment with the aid of two transits.

Anticipating difficulties in closing the upper arm due to the contraction of the river, a timber pile trestle was built similar to the one used in closing the upper arm of the second cofferdam.

The arm progressed rapidly toward closure. When the arm was about 100 ft. from closure, the scour had caused the river bed to be many feet below the original elevation. The Dredge Grafton

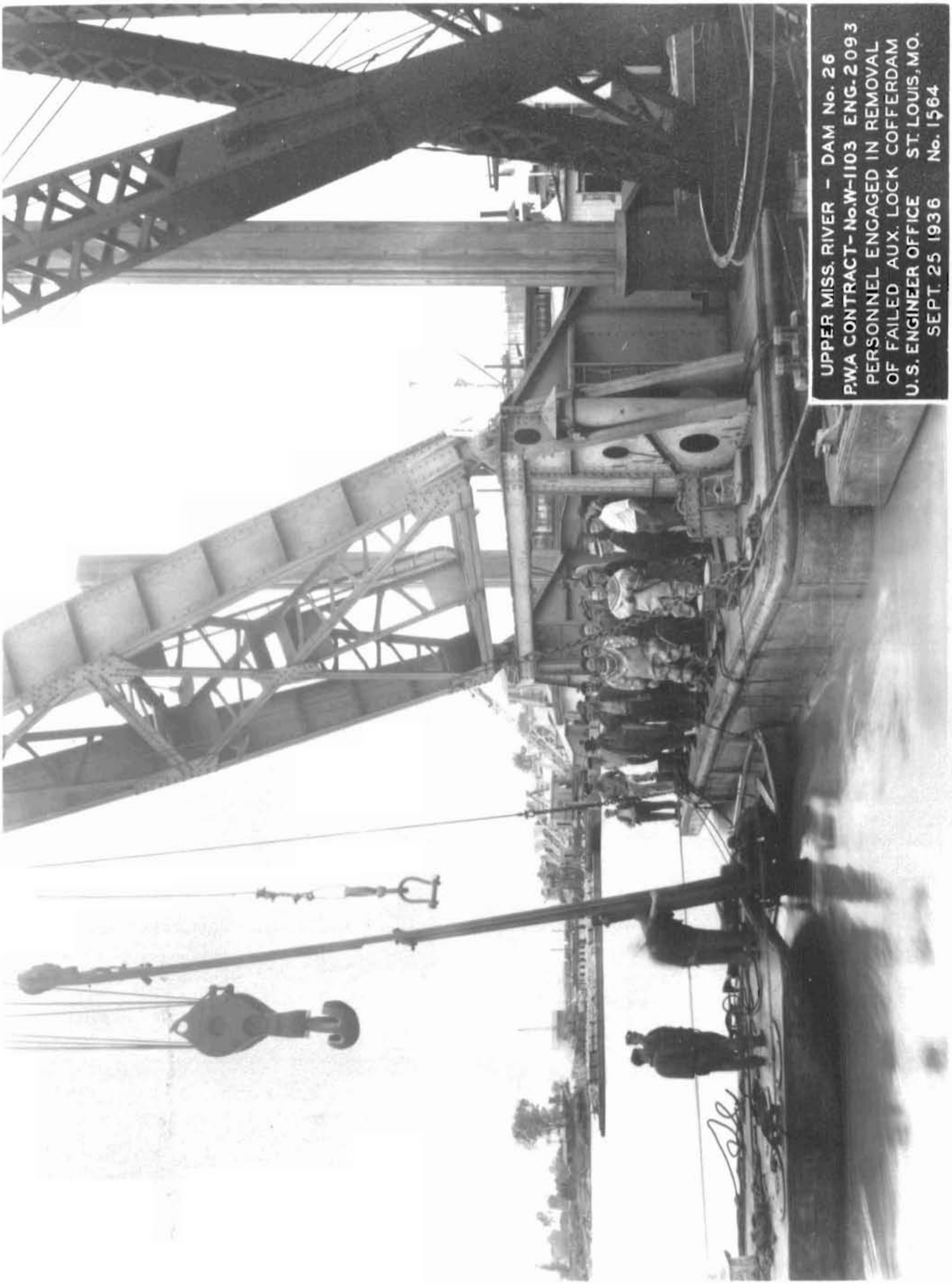

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG. 2093
PERSONNEL ENGAGED IN REMOVAL
OF FAILED AUX. LOCK COFFERDAM
U.S. ENGINEER OFFICE ST. LOUIS, MO.
SEPT. 25 1936 No. 1564

Fig. 10.

and a 14" dredge belonging to the Bolz Dredging Company pumped sand just above the closure. The velocity of the current carried the material through the gap and caused a fill to form a short distance below the gap. The coarser material dropped to the bottom as the water spread into a larger area causing a decreased current velocity. This dredging continued until the closure was made. The elevation of the river bed at this location was then practically back to the original elevation. The contractor paid only partially the cost incurred for this dredging, since the fill placed was necessitated by the dredging and removal of the original lock cofferdam.

The closure was made in similar manner as the closure of the upper arm of the second section, using the trestle for guide and support. (See Fig. 11).

The lower arm was started Nov. 21, 1936 with the driving of the timber pile for falsework, followed with the sheet piling. The lower arm angled down stream from the lower Illinois end of the second cofferdam to the intermediate lock wall. (See Fig. 12) The lock wall acted as the arm on the Illinois side.

Provision was made in the third section for a flume through which the cofferdam could be flooded in an emergency. It was constructed in the lower extremity of the lower arm about 50 ft. from the intermediate wall. Six sheets in the wall were driven to elevation 404.2 about 12 ft. below the elevation of

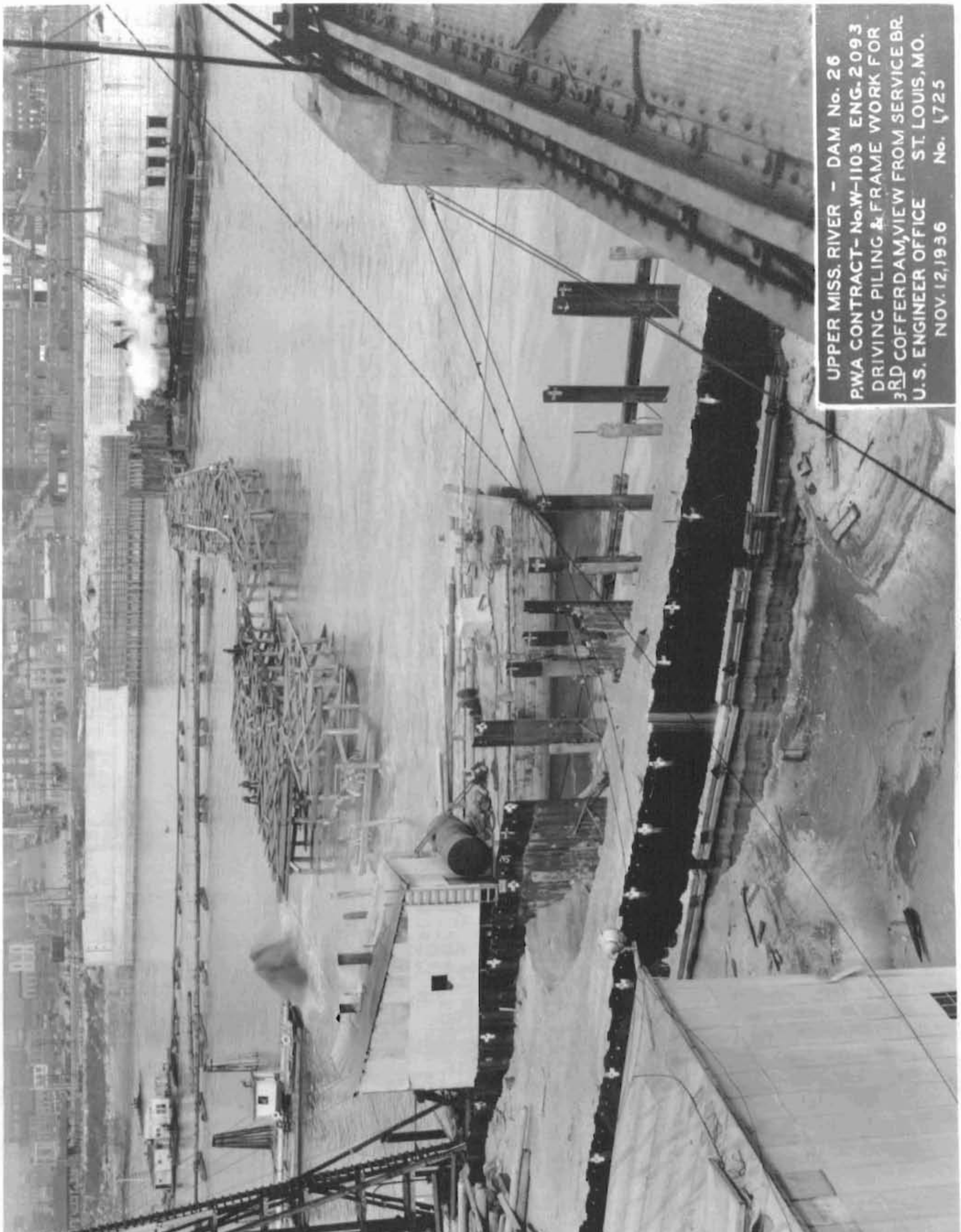

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG. 2093
DRIVING PILING & FRAME WORK FOR
3RD COFFERDAM, VIEW FROM SERVICE BR.
U.S. ENGINEER OFFICE ST. LOUIS, MO.
NOV. 12, 1936 No. 4725

Fig. 11.

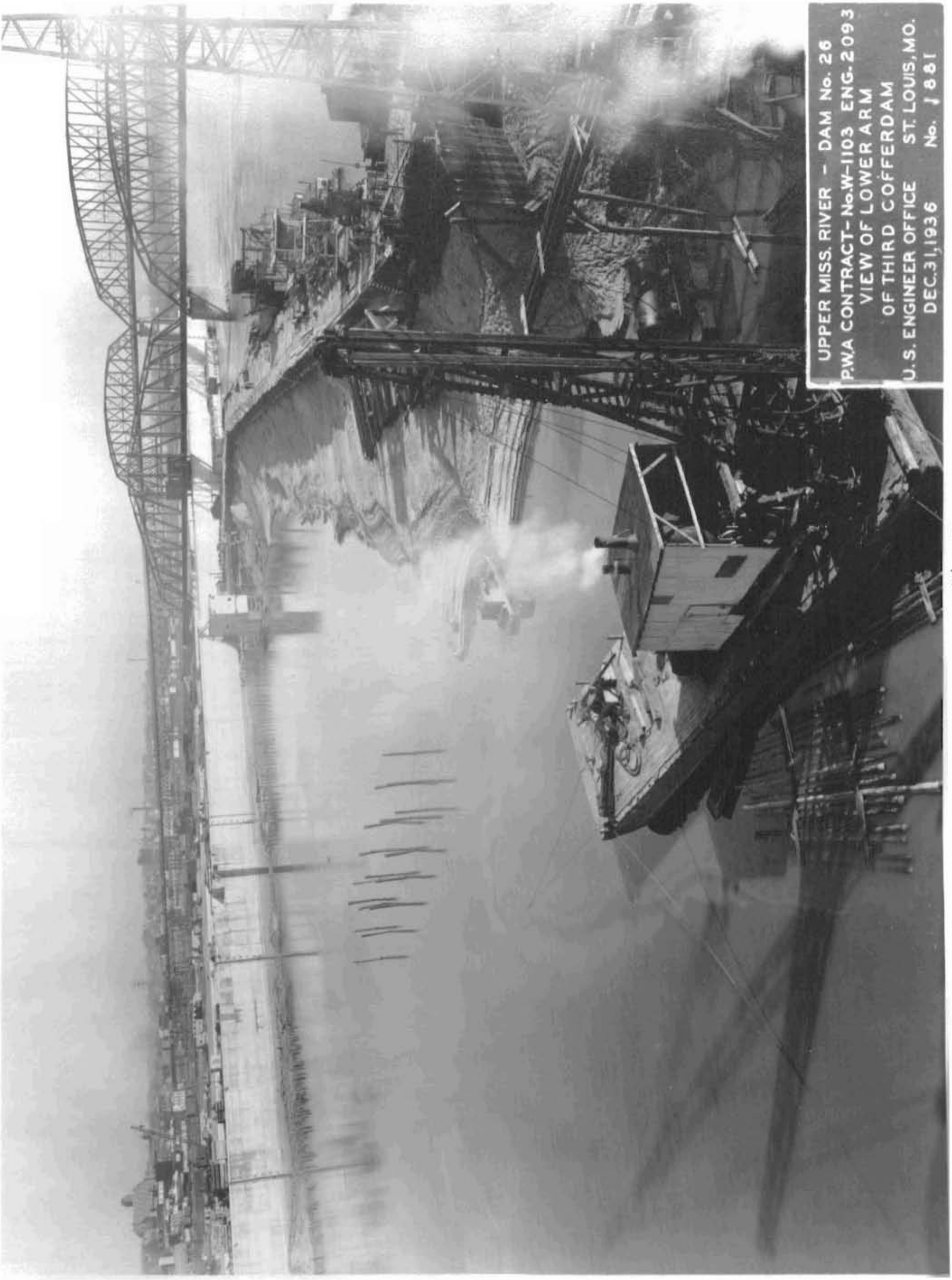

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG-2093
VIEW OF LOWER ARM
OF THIRD COFFERDAM
U.S. ENGINEER OFFICE ST. LOUIS, MO.
DEC.31,1936 No. 1881

Fig. 12.

the rest of the wall, then sheets of approximately 12 ft. were set and threaded on top of the sheets driven to aforementioned elevation. In case of necessity, the sheets could be removed easily and the sand in the wall removed, thus letting in the water. Inside the arm, a sheet metal lined flume was built to carry the water over the supporting berm on the inside to protect it from washing out.

On March 9, 1937, with the upstream gage reading of 414.1 and the downstream reading of 413.0 and the inside reading of 388.44, the flume was opened and the cofferdam inclosure was flooded. The pumps had been stopped on the day previous but the outside river rose so rapidly that seepage was not fast enough to fill the inclosure before the infiltration through the supporting berms weakened them and flooding was necessary. The previously described flume was opened and the inclosure was filled in 7:15 hours to the same elevation as the downstream river. Everything worked satisfactorily and very little damage occurred to the structure.

The opening in the wall formed a typical weir. From calculations the quantity of water required to fill the inclosure was 270 acre feet.

The amount of water passing into the inclosure to raise the inside elevation 16 feet could be measured fairly accurate. When it reached the crest of the weir at elevation 404.02 the rate of rise on the inside decreased.

The following formula was used to determine the amount of water pouring through the opening and it checked very well with the results up to the point when the water elevation reached the crest of the weir, when conditions then were changed:

$$Q = C(Lh)\ 2/3\ \sqrt{2gh}, \text{ where } Q = \text{cu. ft. per sec.}$$

$$C = .4,\ L = 9.75 \text{ ft.},\ h = 8.8 \text{ ft.}, \text{ and } g = 32.2 \text{ ft. per sec.}$$

$$Q = .4(9.75 \times 8.8)\ \ 2/3\sqrt{2 \times 32.2 \times 8.8}$$

$$Q = 545.7 \text{ cu. ft. per sec.}$$

1,964,000 cu. ft. or 45 acre ft. per hour.

After the river receded the gap in the arm was again filled in and the inclosure pumped out.

DEWATERING OF INCLOSURES

Four pumps were used in each of the three cofferdam areas. These pumps operated intermittently, maintaining a desired water level inside the cofferdam, by the use of a float attached to the switch of the motor. Ingersol-Rand pumps of 7500 gallon per minute were used. They were placed at each corner of cofferdam No. 1 approximately 100 ft. from each wall. (See Fig. 1).

These pumps were set up in a 20 ft. circular cell of steel sheet piling driven deep enough to allow the water to flow into the cell. The pumps were lowered to desired elevation and the water pumped over the arms of the cofferdam through 16" pipe.

When the first cofferdam was pulled the two pumps near the Missouri bank were removed. The outer two pumps were in the inclosure between the Missouri arm of cofferdam No. 1. These were left intact and used in the second cofferdam.

The pumps removed from the first section were again set up in the Illinois end of the second section, this time on wood pile. A sump constructed of sheet piling was erected outside of the pumphouse and the intake pipe inserted in this, otherwise the procedure was the same.

In the third section, the pumps removed from the Missouri end of the second section were erected together at the lower Illinois corner, both using the same sump. The two pumps in the

Illinois end of the second section remained intact in the inclosure between the Missouri arm of the third section and the Illinois arm of the second section. When the third cofferdam was completed, these pumps were used in this section.

It was necessary in the first section to maintain a well point system along the Missouri bank in order to keep the bank de-watered, otherwise it slipped into the inclosure and failed to play its part as an arm of the cofferdam.

After the pumps were set up and the cofferdam completed, dewatering of the cofferdam was started. This was not just a case of pumping the water out of the inclosure as quickly as possible. As the water level was lowered a strict vigilance was maintained on the berms. If the berms showed signs of weakness, the pumps were stopped intermittently to maintain a certain level or even stopped altogether to allow a maintenance crew to strengthen the berm. This was done either by clamming sand and placing it on the berm or by men placing two inch stone along the toe of the slope, causing a terrace effect. This process of dewatering was used in each of the three cofferdams, lowering the water until the level required to maintain a dry bottom for foundation work. The water might have been pumped out in one-third the time required but at a sacrifice of the supporting berm. (Fig. 12 shows the effect of placing stone along toe of berm.)

REMOVAL OF COFFERDAMS

Upon completion of the first section of the dam, removal of the cofferdam followed. After all equipment was removed and the debris cleaned up, all the pumps were stopped and the inclosure was allowed to flood by the seepage waters.

A Whirley rig started pulling sheet pile on the lower arm just outside of the Missouri arm of the second cofferdam, which had been driven previous to flooding. The rig worked from this point toward the Missouri bank. A section of the lower arm adjoining the bank was left intact to use as a loading dock. Both inside and outside rows of sheeting were removed with the exception of the bolt sheets. These were removed by a skid rig mounted on a barge, since the Whirley was not equipped to exert as strong a pull as the skid rig.

While the sheet piling were being extracted, the contractor was using a dredge to pump sand for the abutment fill and for filling the Missouri arm of the second cofferdam. Inasmuch as the general contractor's contract with the Bolz Dredging Company, subcontractor for fill and excavation, called for excavation as pay item only when it was necessary to spoil, it was possible to utilize the dredging for removal of sand fill at no cost to the general contractor save as fill for above localities and to facilitate extraction of "bolt" sheets. The dredge pumped the berms and fill from the cofferdam arm before the skid rig started extracting. This rig pulled the bolt sheets just high enough to permit the lower row of walers to be taken off. The wales and bolts were salvaged and left the sheets for the Whirley to extract. The skid rig could not handle the sheets after extraction whereas the Whirley could swing around and deposit the extracted piles on a barge.

In removing wales it was found practical to use a small flatboat in which a couple of men could easily reach the wales, have room for tools, and work in comparative safety. These flatboats were about five feet wide and eight feet long, and had a side about a foot high with a rake at each end. Quite often it was found that the threads on the bolts were bruised and the nuts could not be turned easily. These were cut off with an oxyacetylene torch. It was feasible to put the oxyacetylene tank in the boat so that the men could use the torch whenever necessary.

The skid rig was also used to extract the timber guide piles which were 20 ft. center to center. The bracing between guide piles had been removed during the construction of the cofferdam just before filling the arm with sand.

After the lower arm of the cofferdam was extracted, practically the same procedure was followed in extracting the upper arm. The Whirley used on the lower arm, with boom lowered was pushed up under a raised Tainter gate of the dam to the inside of the upper arm. It started to extract the riverward end and inside wall of the upper arm, working toward the Missouri bank.

Another Whirley crane was used to extract the outside wall, working opposite the one inside. Both left the "bolt" sheets in place until the dredge disposed of the cofferdam fill around them. On this arm instead of leaving the bolt sheets for the skid rig to extract, both Whirleys extracted simultaneously on the sheets that were bolted together. The wales and bolts were taken out in the same manner as those on the lower arm. The wales were tied to the barges and made into rafts while the bolts were put on the barges and later transferred to the dock to be straightened and rethreaded, where necessary, for use in the next unit. Another skid rig was used to pull the timber guide piles. These timber piles were placed on a barge tied along side the skid rig barge for that purpose.

On the whole, the sheet piling were extracted very easily. Quite often it took less than thirty seconds to extract one pile after the extractor was pinned to it. In fact, most of the time was consumed in the operation of swinging the crane around, lowering the sheet to the barge, extracting the safety pin and removing the pin. In a few rare cases when a sheet was hard to pull it was left for one of the skid rigs to start it up for the crane. (Fig. 13 shows a Vulcan #400 during extraction of a sheet pile.)

Extraction of lower cofferdam arm was started on Mar. 3, 1936 and was completed on March 10th. Pulling of the upper arm was started on March 10th and completed March 25th.

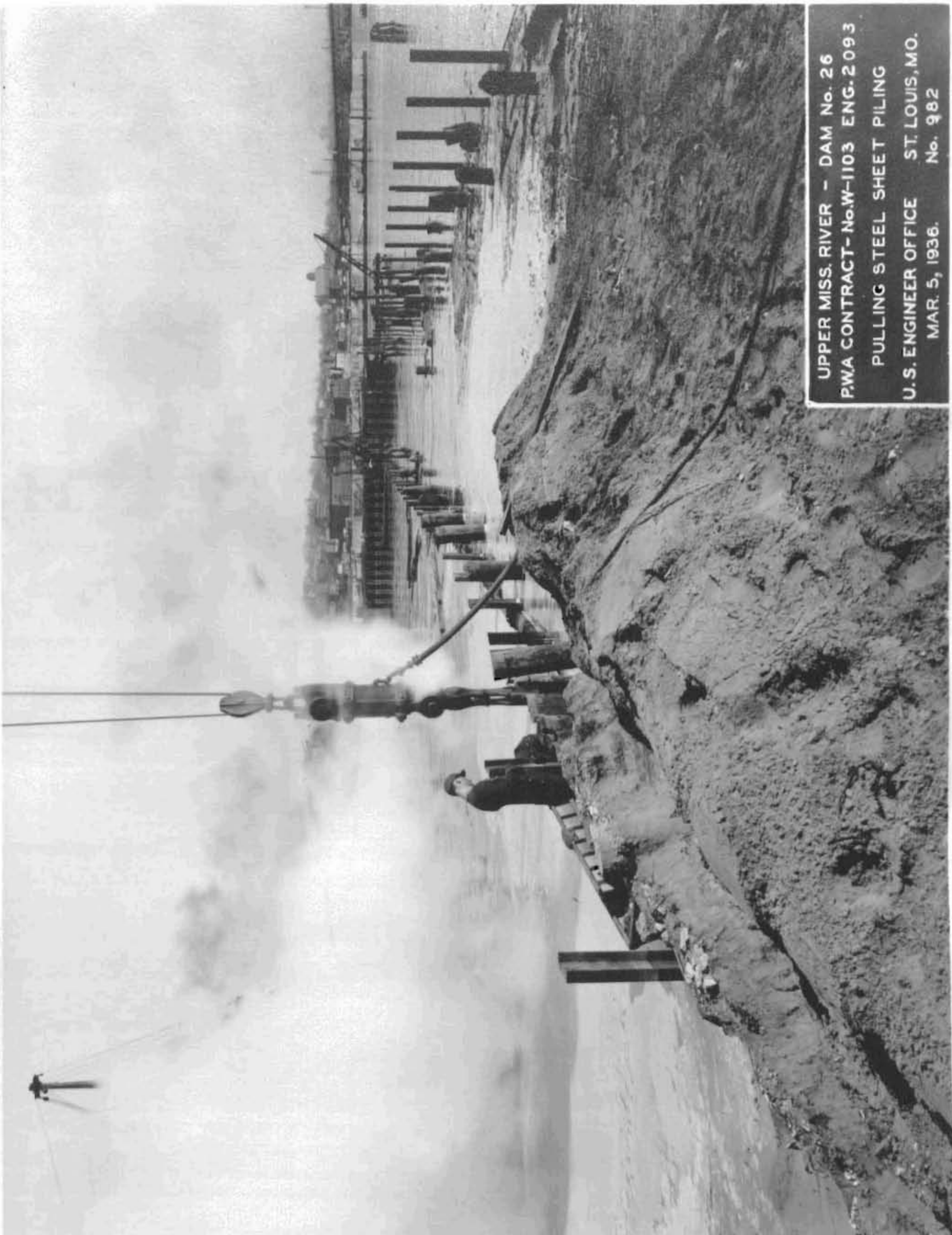

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT-No.W-1103 ENG.2093
PULLING STEEL SHEET PILING
U.S. ENGINEER OFFICE ST. LOUIS, MO.
MAR. 5, 1936. No. 982

Fig. 13

After the upper arm of the second cofferdam was constructed with approximately 170 ft. of the Illinois arm, a Whirley crane and a skid rig followed what may be termed standard procedure in removing the Illinois arm of the first cofferdam. Not until this time were rigs available to do this work as failure of a section of the upper arm had seriously complicated the construction procedure and necessitated longer use of all floating equipment for remedial work. Extraction was started on this arm May 18, 1936 and completed June 11, 1936. However, these rigs did not work continuously on this extracting.

The second cofferdam inclosure was flooded on October 23, 1936 and extraction of the sheeting in the upper arm was started October 26, 1936. The same procedure was used as on the first cofferdam with the exception that removal of the downstream arm was made at the same time as the upstream arm. (See Fig. 14 aerial photograph showing partial removal of second cofferdam.) The dredge removed the berms of these walls, placing the fill in the Missouri arm of the third cofferdam. Removal of the Missouri arm of the second cofferdam was started Nov. 2, 1936 and removal of the Illinois arm was started Nov. 9, 1936. The fairly low stage of the river made possible the removal of all the arms of the second cofferdam at the same time. This was not feasible in the first. However, the upper arm of the third cofferdam was under construction when the Illinois arm of the second

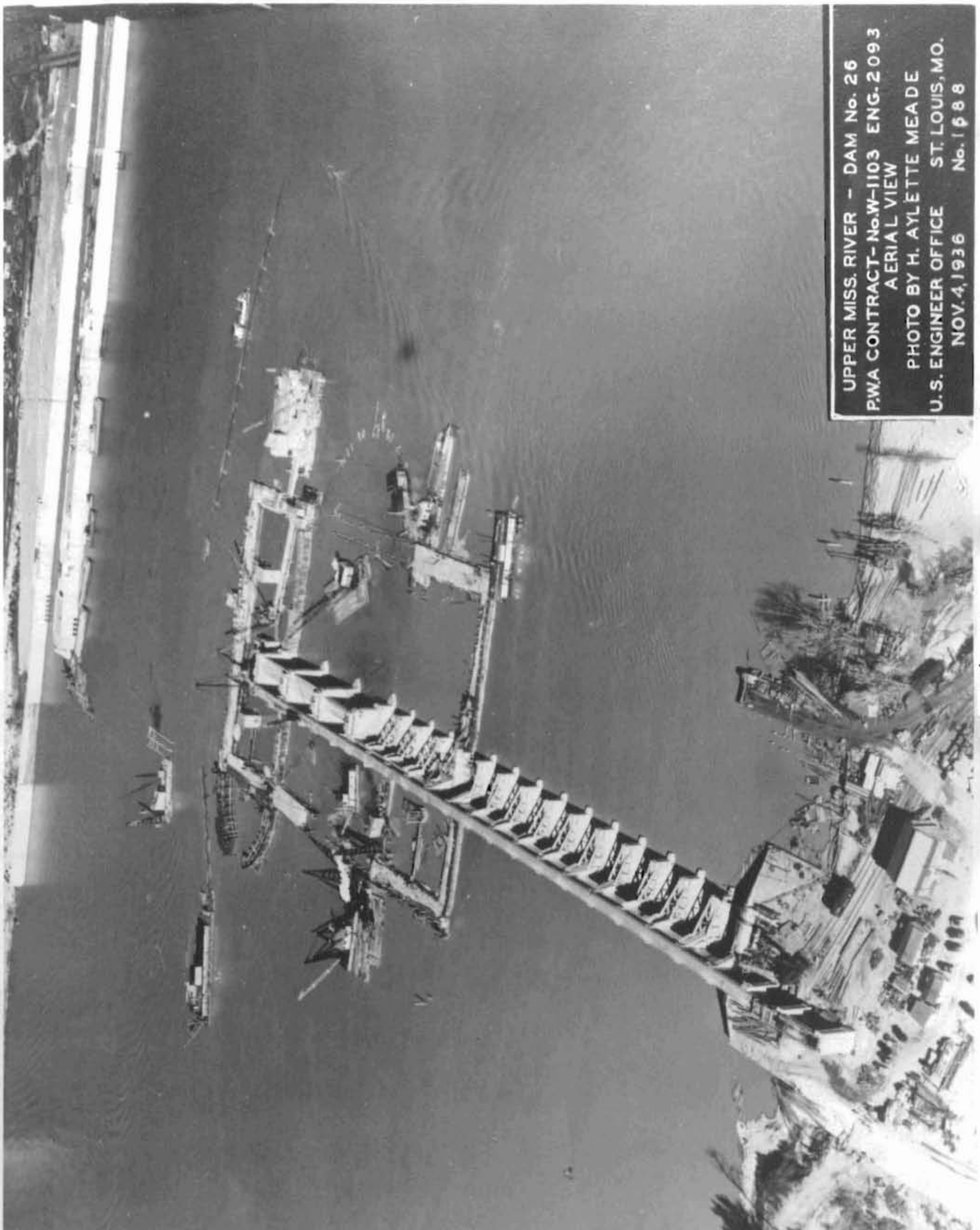

UPPER MISS. RIVER - DAM No. 26
P.W.A CONTRACT- No.W-1103 ENG. 2093
AERIAL VIEW
PHOTO BY H. AYLETTE MEADE
U.S. ENGINEER OFFICE ST. LOUIS, MO.
NOV. 4, 1936 No. 1688

Fig. 14

cofferdam was started to be removed. On December 2, 1936 all pile in the second cofferdam had been removed.

The third cofferdam inclosure was flooded on Sept. 20,1937 and extraction of the sheeting was started on Sept. 24, 1937. The usual procedure was used on the removal of this cofferdam. The removal of all the walls was started at practically the same time since all equipment had been removed. The dredge removed the berms and spoiled them.

The steel sheeting was trimmed and sorted as to type and size. Thus the used sheeting was salvaged after being used on an average of three times.

The third cofferdam was completely removed by December 21, 1937.

COSTS

The contract called for payment of cofferdam at $300 per linear foot of work inclosed. It was to the advantage of the contractor to be as economical as possible in inclosing the area about the permanent structure. In planning the area to be inclosed in each section of cofferdam, allowance was made for materials and equipment to be used in the section.

The length of the inclosure had no bearing on the economy of constructing the cofferdam because the upper and lower arms of the three cofferdams approximated the total length of inclosed work. The width of the inclosure was the factor with which to be reckoned. If the entire dam could have been inclosed with one cofferdam, disregarding the problem confronted by confining the river to the lock, it can readily be seen that no arms would have been necessary from the upper arm of the cofferdam to the lower, effecting a saving in construction and removal and maintenance of four of these cross arms. Such was not possible due to the necessity of keeping an open channel for navigation and the necessity of passing a large volume of water around the dam under construction. The amount of infiltration varied as to the perimeter of the cofferdam and not as to the area. Some water percolated from beneath the walls but a good portion seeped through the wall itself.

In the first section, total cost of maintenance, construction and removal approximated the contract price. The total cost in the second section exceeded by about one-third the contract price. This was due in part to the necessity of one more arm being constructed, maintained and removed and to the failure in the upper arm, which cost approximately $17,000. The cost on the third section was below the contract price. This was due to the fact that the contractor was able to inclose the third section of the dam and the riverwall of the twin locks, which was in a different contract. The inclosed work on the dam was measured across the river, whereas the inclosed work on the lock wall was measured up and down the river, making a sum total of inclosed work much more than the length of the inclosure measured in either direction. The total cost on all cofferdams was approximately the same as the contract price. There were 1816 ft. on inclosed work on the dam at $300 per linear foot and 820 ft. of inclosed work on the lock at $300 per linear foot.

Since actual costs cannot be presented herein, the several items in each operation in the construction and removal of the three cofferdams are broken down in percent of cost on each section as follows:

Construction and maintenance of first cofferdam

Handling Materials	--	Labor	1.64%
		Plant	.25%
Erection	--	Labor	8.95%
		Plant	2.92%

Pumps and Sumps	--	Labor	1.77%
		Plant	.49%
		Materials	1.03%
Scouring Protection	--	Labor	.52%
		Plant	.44%
		Materials	.56%
Materials for Construction	--	Piles, rods, wales, etc.	15.10%
Dewatering and Maintenance	--	Labor	17.98%
		Plant	7.75%
		Power	4.41%
		Materials	.96%
Cost of Dredging	--		11.27%
Overhead	--		23.96%
		Total	100.00%

<u>Construction and Maintenance of Second Cofferdam</u>

Handling Materials	--	Labor	.88%
		Plant	.54%
Erection	--	Labor	10.06%
		Plant	2.80%
Pumps and Sumps	--	Labor	1.41%
		Plant	.26%
		Materials	1.05%

Scouring Protection	--	Labor	.49%
		Plant	.09%
		Materials	.72%
Materials for Construction	--	Piles, rods, wales, etc.	27.31%
Dewatering and Maintenance	--	Labor	5.42%
		Plant	2.87%
		Power	2.36%
		Materials	.06%
		Miscellaneous	.05%
Cost of Dredging	--		14.55%
Cost of Failure	--		8.14%
Overhead	--		20.94%
		Total	100.00%

Construction and Maintenance of Third Cofferdam

Handling Materials	--	Labor	1.27%
		Plant	1.41%
		Miscellaneous	.02%
Erection	--	Labor	9.47%
		Plant	2.68%
Pumps and Sumps	--	Labor	2.41%
		Plant	.23%
		Materials	2.89%

Scouring Protection	--	Labor	.55%
		Plant	.08%
		Materials	.91%
Materials for Construction	--	Piles, rods, wales, etc.	27.40%
Dewatering and Maintenance	--	Labor	3.25%
		Plant	1.59%
		Materials	.10%
Cost of Dredging	--		24.47%
Cost incurred preparing for and flooding			3.14%
Overhead	--		18.13%
		Total	100.00%

Removal of First Cofferdam

Removal	--	Labor	52.30%
		Plant	19.87%
		Materials	.03%
		Miscellaneous	.03%
Cost of Dredging	--		1.14%
Overhead	--		26.63%
		Total	100.00%

Removal of Second Cofferdam

Removal	--	Labor	49.65%
		Plant	17.28%
		Materials	.20%
Cost of Dredging	--		8.02%
Overhead	--		24.85%
		Total	100.00%

Removal of Third Cofferdam

Removal	--	Labor	48.60%
		Plant	18.36%
		Materials	.30%
Cost of Dredging	--		8.54%
Overhead	--		24.19%
		Total	100.00%

STEEL QUANTITIES COFFERDAM NO.1

		M 115 36#/ft.			T 12A & 12B T-sections 68#/ft.			x-12A & x-12B 102#/ft.	
	Lengths	37'	50'	60'	37'	50'	60'	60'	Total
Upper Arm	Outside	36	397	64		2		3	502
	Inside	389	77		4			2	472
	Diaphragms	35	1	18					54
	Totals	460	475	82	4	2		5	1028
Illinois Arm	Outside			221			3		224
	Inside	205	15		3				223
	Diaphragms	54							54
	Totals	259	15	221	3		3		501
Lower Arm	Outside	34	414	18		2		2	470
	Inside	396	49		3	1		2	451
	Diaphragms	18	18	18					54
	Totals	448	481	36	3	3		4	975
	Streamline Fin			81					81
Total No. of Sheets		1167	971	420	10	5	6	9	2585

Fig. 15

STEEL QUANTITIES IN SECOND COFFERDAM

		M115 36#/ft.						T-sections T12A T12B 68#/ft			X-Sections X12A X12B 102#/ft		
	Lengths	37'	50'	60'	62'	70'	85'	37'	50'	60'	60'	90'	Total
Missouri Arm	Outside	40	43	97									180
	Inside	194											194
	Totals	234	43	97									374
Illinois Arm	Outside			227						3	1		231
	Inside	47	178					1	2				228
	Diaphragms	13	41										54
	Totals	60	219	227				1	2	3	1		513
Upper Arm	Outside			253	7	43				1	3		307
	Inside	79	193	6				2	1		1		282
	Diaphragms			18									18
	Totals	79	193	277	7	43		2	1	1	4		607
Lower Arm	Outside	229	78					1	1				309
	Inside	265	41										306
	Diaphragms	36	18	18									72
	Totals	530	137	18				1	1				687
Cell	Total			34			34	1	1			2	72
Missouri Fin	Total			75									75
Illinois Fin	Total						102	2	2				106
Total sheets		903	592	728	7	43	136	7	7	4	5	2	2434

Fig. 16

STEEL QUANTITIES IN THIRD COFFERDAM

		M 115 36#/ft.							T-sections T12A & 12B 68#/ft.		
	Lengths	24.5'	30'	35'	37'	50'	60'	70'	37'	50'	Total
Missouri Arm	Outside	7	2		37	69	75				190
	Inside	5	2		146	34					187
	Totals	12	4		183	103	75				377
Upper Arm	Outside					187	217	25	2		431
	Inside				393	77			2		472
	Totals				393	264	217	25	4		903
Lower Arm	Outside				230	128	122			1	533
	Inside				291	139	62		1		540
	Totals				521	267	184		1	1	1073
Missouri Fin	Total						96				96
Total Sheets		12	4		1097	634	572	25	5	1	2350

Fig. 17

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